PATENT SPECIFICATION

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(54) IMPROVEMENTS IN OR RELATING TO COMMUNICATIONS TRANSMISSION SYSTEMS

(71) We, SIEMENS AKTIENGESELLSCHAFT, a German Company of Berlin and Munich, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to communications transmission systems of the type using coded pulses, in particular for identification systems in which a first code word is formed for a logic "1" and a second code word for a logic "0", at the transmitting end, and the two code words are combined with one another in such a manner that commencing from the first code word the second code word is formed by exchanging logic "0" and logic "1" values of the first code word complementary code word), whilst at the receiving end autocorrelation (pulse compression) is carried out, followed by comparison with a threshold voltage.

The German Patent Specification No. 1,261,907 describes means used in order to improve the range resolution of a radar system, by utilising pulse compression. Two pulse trains are constructed in the form of code words transmitted successively in which the distribution of the individual elements is determined in a specific manner in relation to one another. This distribution is contrived in such a fashion that with sequential numbering of the code words, the even code words yield an autocorrelation function which differs from that of the odd numbered code words, and is in antiphase with the prime maximum. Each second one of the autocorrelation functions formed at reception additionally experiences a phase reversal, and this is followed by summing of the two autocorrelation functions. In so doing, it is contrived that the prime maxima are superimposed cophasally, whilst the relationship of the even numbered to the odd numbered code words is so arranged that secondary maxima formed during pulse compression mutually cancel one another.

Because the known method is used to improve the range resolution, it is sufficient as far as the received signals are concerned to arrange for the provision of a threshold after the autocorrelation phase, and to evaluate pulses which exceed this threshold as genuine echo signals, whilst suppressing the rest.

In the transmission of information, e.g. a code message or identification signal, a responding station has to transmit to an interrogating station a communication whose information content has to be determined at the interrogating station by decoding. Thus, in contrast to the requirements of simple plotting procedures, it is not sufficient in these latter cases simply to determine whether a response signal is above or below a threshold.

The German Patent Specification No. 1,260,565, describes a system in which the effect is to transmit a logic "1" using a code word which consists of several individual elements arranged in an arbitrary sequence. The logic "0" in this same system, is formed by substituting the elements "0" and "1" for each other in the code word for the logic "1" (i.e. thus forming the complementary code word). For example, if the code word 10110 is provided for the logic "1", then the associated logic "0" will be represented by the code word 01001. In this method, there is no restriction on the choice of the code words, i.e. all code words are regarded as permissible. Any problems due to secondary maxima occurring during correlation are not dealt with.

In pulse compression (autocorrelation), although relatively high signal to noise ratios can be achieved relatively to any intentional unwanted interference, these signal to noise ratios are impaired by the fact that during correlation (pulse compression) so-called secondary maxima occur whose magnitudes depend upon the nature and length of the particular code word.

One object of the present invention is to provide the most undisturbed possible transmission of information, whilst at the same time excluding as far as possible the dis-

turbing influence of secondary maxima occurring during correlation.

The invention consists in a communications transmission system using coded pulses, in which means are provided at the transmitting end to form a first code word for a logic "1" and a second code word for a logic "0", the two code words being related to one another in that, commencing from the first code word the second code word is formed by substituting logic "0" for logic "1" values of the first code word and vice versa to form a complementary code word and means are provided at the receiving end to perform autocorrelation by pulse compression followed by comparison with a threshold voltage, each code word being composed of two equilength code word sections comprising individual elements which are so chosen and which are so combined after pulse compression that their autocorrelation functions yield the same sign in the prime maximum zone, and yield the same amplitudes but opposite signs in any secondary maxima zone, and in that for the first autocorrelation function corresponding to a logic "1", a first threshold with a first threshold value is provided, and for the second autocorrelation function, corresponding to a logic "0", a second threshold with a second threshold value is provided, the second threshold value having the opposite sign to the first.

In this fashion, whilst avoiding unwanted secondary maxima, it is possible to achieve information transmission of a kind in which ensures a very high degree of security against any intentional unwanted interference during decoding. Reliable information transmission is thus ensured, even in the case of low transmitter powers, or low received signal strengths. Advantageously additional criteria may be provided in order to distinguish the code word sections which form a code word. A particularly simple solution here is that of assigning to or modulating on to a first code word section, a first frequency, and assigning to or modulating on to the second code word section a particular other frequency. The separation of the code word sections can then be effected quite simply by means of filters.

It is also possible, especially when the available bandwidth is restricted, to provide individual address signals for the separation of the code word sections, which signals are not employed for correlation. The first code word section in each case receives a specific, unchanging first address, and the second code word section receives a specific, unchanging second address. These addresses must be so chosen that they cannot be confused with components of the code word sections.

Another advantageous possibility for distinction of the code word sections is to provide counter circuits which makes it possible, if the duration of the code word sections is known, to determine their commencement and end. This method of distinguishing however, can only be implemented if a certain synchronism exists or is created between the transmitting and receiving stations.

The invention will now be described with reference to the drawings in which:

Figure 1 schematically illustrates two code word sections and their autocorrelation functions;

Figure 2 is a table showing an example of a piece of coded information;

Figure 3 is a block schematic circuit diagram showing the transmitting end design of one exemplary embodiment of a communications transmission system constructed in accordance with the invention;

Figure 4 is a block schematic circuit diagram showing the receiving end design for this exemplary embodiment of a communications transmission system constructed in accordance with the invention;

Figure 5 is a table showing the profile of the information described in Figure 2, after carrying correlation; and

Figure 6 illustrates details of one suitable analyser circuit.

In row *b* of Figure 1, a code word section *a* is indicated, having the following composition;

$$+ + + - - - + -$$

Thus, the code word section *a* consists overall of eight individual elements. After execution of the autocorrelation process, there is obtained for this code word section a time function which has been shown at the right-hand end of row *b*. In addition to a clearly defined maximum EMa, there is a series of secondary maxima which have different amplitudes and signs.

In row *c* of Figure 1, a code word section a^*, with eight individual elements is shown, which has the following composition:

$$+ + + - + + - +$$

After carrying out autocorrelation, a function with a clearly defined maxima EMa* and a series of secondary maxima, is produced. The code word section a^* is chosen in a specific manner in relation to the code word section *a*, indeed in such manner that it has the same number of elements as the code word section *a*. Moreover, the code word section a^*, in comparison with the code word section *a*, satisfies the supplementary condition that while having prime maxima of the same magnitude the secondary maxima, although occurring at the same positions and having the same amplitudes, have opposite signs.

If the autocorrelation functions (AKF)

shown in rows b and c of Figure 1 are combined to form a sum function, as illustrated in row d of Figure 1, then it is evident that the secondary maxima all cancel one another out and a clear prime maximum EMa+EMa* occurs.

Details concerning the existence and number of such pairs of words, are available from literature on the subject, for example, in the article "Complementary Series" published in IRE Translations on Information Theory, April 1961, pages 82—87.

The coding of the individual elements can be carried out using known coding techniques, e.g. frequency shift keying (FSK) phase shift keying (PSK) or differential phase shift keying (DPSK). By way of example, in respect of the code word sections a and a^*, phase shift keying has been indicated in the bottom boxes. At decoding, in all cases a bipolar signal will appear.

In the table shown in Figure 2, a piece of code information made up of logic "1", and logic "0" elements is indicated in the topmost row, which information is to be transmitted by a communications transmission system, generally a responder unit (e.g. a transponder) to an interrogating unit (e.g. a secondary radar device). Here, commencing from the notations of Figure 1, the following conventions apply:

a and a^* are code word sections of the kind characterised in Figure 1, i.e. their secondary maxima cancel one another out and their prime maxima are superimposed upon one another;

$\bar{a}$ is obtained from a by substituting zeros for ones and vice versa; and

$\bar{a}^*$ is similarly obtained from a^*.

The term (ab) will be used to designate the correlation function between the words a and b, i.e. a is correlated with b, b being the reference code word.

Then, we have the following condition:

$$(aa)=(\overline{aa})=-(a\bar{a})=-(\bar{a}a);$$

and the same relationships will also apply if in each case a^* is used instead of a.

In respect of the example shown in Figure 2, it has been assumed that the two code word sections which together form a code word, are transmitted at two different frequencies. Thus, to the particular first code word section a or $\bar{a}$ of a full code word, the frequency $f1$ is assigned and to the second code word section a^* or $\bar{a}^*$ of a full code word, the frequency $f2$ is assigned. The signalling system is contrived so that a logic "1", in accordance with the top row of Figure 2, is assigned the code word sections a and a^*, and a logic "0" is assigned the two code word sections $\bar{a}$ and $\bar{a}^*$. For a distribution in the form of a piece of code information with the following structure, for example:

1011100

then in the second row the sequence of the code word sections has been given and in the third row the associated frequency $f1$ or $f2$.

Figure 3 shows the arrangement for producing the coded information at the transmitting end. The information for transmission, e.g. the code of a vehicle, is supplied in the present example as the code word illustrated in the top row of Figure 2, to a code store CS in which the code word sections a, a^*, $\bar{a}$ and $\bar{a}^*$ are held. It may suffice if the corresponding code word sections a and a^* are stored in the code store CS, because the code word section $\bar{a}$ and $\bar{a}^*$ can be derived quite simply from the former, by substitution of the "0" by "1" elements, and vice versa. The code store CS also contains control devices which supply the code word sections a, a^*, $\bar{a}$ and $\bar{a}^*$ at the correct time to the correct output, in accordance with the information to be transmitted (in the present example 1011100).

On the assumption that distinction of the code word sections is to be effected by the use of two different carrier frequencies $f1$ and $f2$, then two separate oscillators are provided whose oscillations are modulated onto the code word sections in a corresponding fashion, e.g. by phasing (PSK). Details of the modulation circuits have not been shown here because the techniques are already known *per se.* Two transmitter oscillators O1 and O2 have been schematically shown, these producing carrier frequencies $f1$ and $f2$ respectively. The frequencies furnished by the transmitting oscillator O1 are modulated in a mixer Ma in accordance with the individual elements of code word section a, and in a mixer M$\bar{a}$ in accordance with the individual elements of the code word section $\bar{a}$. The elements of the code word section a^* are modulated in a mixer Ma^* onto the frequency $f2$ produced by the transmitter oscillator O2, as are those of the code word section $\bar{a}^*$ in a mixer M$\bar{a}^*$. The transmitter signals thus obtained are fed through respective buffer amplifiers TV or other decoupling arrangements to a common antenna SA which then radiates them.

It is possible to simultaneously radiate the

corresponding code word sections, e.g. $a\,a^*$ and $\bar{a}\,\bar{a}^*$, because they can be distinguished from each other by the different carrier frequencies $f1$ and $f2$. If the code word sections are modulated onto the carrier frequencies successively, then it has to be ensured at the receiving end that after demodulation the corresponding code word sections are furnished simultaneously so that correct superimposition of the autocorrelation functions is possible.

To control the code word sections, a pulse generator in the form of a clock U is provided, which also makes it possible to make provision to prevent any jamming by enemy simulation of signals by changing from time to time to use other pairs of code word sections to represent "0" and "1" values.

Figure 4 shows the related receiver equipment, which possesses a receiving antenna EA. It is possible to use the transmission system in accordance with the invention for line tranmission applications although then the risk of intentional or inadvertent interference is substantially less marked than it is with radio transmission.

The received signals, possibly in the intermediate frequency position, are passed to parallel-connected filters F1 and F2, the filter F1 only passing the frequency $f1$ and the filter F2 only passing the frequency $f2$. The filters F1 and F2 can be followed, in a manner known *per se*, by further demodulation devices. The demodulated received signals are fed to respective pulse compression networks PKa and PKa^*. These pulse compression networks effect compression of the long code word sections into signal functions of the kind shown in the first two rows of Figure 1 (autocorrelation). Although, overall, four code word sections a, $\bar{a}$, a^* and $\bar{a}^*$ are used, it is sufficient here if each of these pulse compression networks has a single reference code. For example, for the pulse compression network PKa the reference code a can be used, and for the pulse compression network PKa^* the reference code a^*. It is equally possible, however, to use for PKa the reference code $\bar{a}$ and for PKa^* the reference code $\bar{a}^*$. The output signals of these pulse compression networks PKa and PKa^* each exhibit well defined maxima of the same sign, whilst their secondary maxima exhibit opposite signs of the same respective amplitudes. This fundamentally correct sign, as already illustrated in Figure 1, is achieved by virtue of the fact that the code word section a is correlated with the reference code word a and the code word section a^* with the reference code word section a^*. It is also possible to adopt the reverse procedure so that the code word section a is correlated with the reference code word $\bar{a}$ and the code word section a^* with the reference code words $\bar{a}^*$. Generally speaking, this means that the reference code words, in the case of the two corresponding code word sections, should be linked by the same relationship with the associated code word section. If the autocorrelation functions of the two code word sections of a complete code word initially have the correct sign, then the inclusion of an inverter, which is otherwise required, can be dispensed with.

If the pairs of corresponding code word sections are not transmitted simultaneously, but successively, the leading channel must contain a delay device VL which will delay the code word section first transmitted by the duration of a code word section so that the prime maxima corresponding to Ma and Ma* of Figure 1, coincide. The resultant signals from channel I and channel II are applied to an adder device AE and, in the manner shrown in Figure 1 the secondary maxima cancel one another out whilst the correspondingly large prime maximum is produced.

In Figure 5, in the top rows, the correlation functions linking the individual code word sections in accordance with the distribution shown in Figure 2 have been indicated. At a terminal C, forming the output of the adder device AE of Figure 4, the pulses illustrated at the centre are obtained. Here, the logic "1" of the received code information is represented by a positive amplitude value, and the logic "0" by a negative amplitude value.

The conversion of the signal train shown in row 3 of Figure 5, to form a distribution of logic "1" elements in a first channel and logic "0" elements in a second channel, is illustrated in greater detail in Figure 6. The signals corresponding to row 3 of Figure 5, i.e. coming from the output terminal C, of Figure 4, are applied to two parallel-connected threshold circuits PSW and NSW. The threshold circuit PSW has a positive threshold, indicated in the timing diagram of Figure 6 by a broken-line S1. The threshold circuit NSW has a negative threshold value S2, shown as a broken-line. Thus, at the output of PSW, the logic "1" values appear, and at the output of NSW the logic "0" values appear. In this way, the information 1011100 is transmitted from the transmitter station of Figure 3 to the receiving station and can here be correspondingly displayed on display equipment (not shown), or fed for analysis by a computer (not shown). The threshold values S1 and S2 can be set very high so that good interference suppression is achieved. Both the values will conveniently be approximately the same in magnitude.

With corresponding design of the code store CS shown in Figure 3, it is possible, as already mentioned, to change the code word sections a and a^* from time to time and therefore also change $\bar{a}$ and $\bar{a}^*$. This is particularly important if there is any risk that the transmitted signal trains could be subjected to monitoring for a protracted period of time, and subsequently deliberately simulated by an enemy for jamming purposes. With a corresponding change in the code word sections at the transmitting end, at the same time and in synchronism therewith, a new reference code must be set up at the pulse compression networks PKa and PKa^*, in accordance with Figure 4, in order that the correct autocorrelation functions are obtained. Thus, here too, in order to control the reference codes, a clock U is provided, which sets up corresponding reference codes in the pulse compression filters PKa and PKa^*, which codes will conveniently be extracted from a store similar to CS (not shown in Figure 4).

The communications transmission system described is particularly advantageous in situations where short pulse telegrams are to be transmitted, as for example is preferably the case in code signals systems, e.g. in secondary radar work.

WHAT WE CLAIM IS:—

1. A communications transmission system using coded pulses, in which means are provided at the transmitting end to form a first code word for a logic "1" and a second code word for a logic "0", the two code words being related to one another in that, commencing from the first code word the second code word is formed by substituting logic "0" for logic "1" values of the first code word and vice versa to form a complementary code word, and means are provided at the receiving end to perform autocorrelation by pulse compression, followed by comparison with a threshold voltage, each code word being composed of two equi-length code word sections comprising individual elements which are so chosen and which are so combined after pulse compression that their autocorrelation functions yield the same sign in the prime maximum zone, and yield the same amplitudes but opposite signs in any secondary maxima zone, and in that for the first autocorrelation function corresponding to a logic "1", a first threshold with a first threshold value is provided, and for the second autocorrelation function, corresponding to a logic "0", a second threshold with a second threshold value is provided, the second threshold value having the opposite sign to the first.

2. A communications transmission system as claimed in Claim 1, in which both said threshold values are made equal in magnitude.

3. A communications transmission system as claimed in Claim 1 or Claim 2, in which the reference code words utilised in pulse compression for two corresponding code word sections are each linked by the same relationship with the associated code word section.

4. A communications transmission system as claimed in any preceding Claim, in which each code word section forming a code word is made distinguishable by virtue of the fact that said sections are each assigned different frequencies.

5. A communications transmission system as claimed in Claim 4, in which two different frequencies are provided, of which the first in each case applies to the first code word section and the second applies to the second code word section of a code word.

6. A communications transmission system as claimed in any one of Claims 1 to 3, in which each code word section forming a code word is made distinguishable by providing individual address signals which precede the respective code word sections, but which are not employed in correlation.

7. A communications transmission system as claimed in any one of Claims 1 to 3, in which the code word sections which form a code word are made distinguishable by the provision of counter circuits which are set to the duration of the code word sections, and so determine their commencement and end.

8. A communications transmission system as claimed in any preceding Claim, in which all the code words used have the same number of individual elements.

9. A communications transmission system as claimed in any preceding Claim, in which a change in the composition of the code word sections is effected from time to time at the transmitting end by means of a clock and at the receiving end the reference codes of the pulse compression networks are changed at the same operationally effective times.

10. A communications transmission system as claimed in Claim 9, in which the clocks at the transmitting and receiving ends are provided with synchronising means to ensure operationally effective simultaneous modification of the codes.

11. A communications transmission system as claimed in any preceding Claim, in which there are provided at the receiving end two parallel-connected receiver channels, each of which contains a pulse compression network assigned a reference code, and in that in one channel code word sections of the first type and the complementary code word sections are processed, whilst in the second channel code word sections of the second type and their associated complementary code word sections are processed.

12. A communications transmission system as claimed in Claim 11, in which serial trans-

mission of the corresponding code word sections is employed, and a delay device is provided in the receiving channel carrying the first code word section, the delay of which device corresponds to the duration of a code word section.

13. A communications transmission system substantially as described with reference to Figures 3 and 4.

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1504118 COMPLETE SPECIFICATION

3 SHEETS This drawing is a reproduction of the Original on a reduced scale

Sheet 1

Fig. 1.

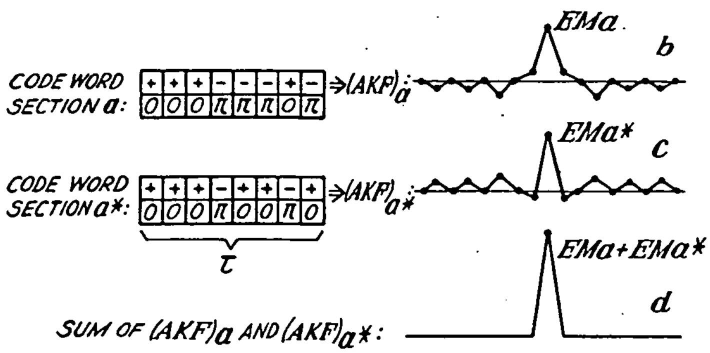

Fig. 2.

CODE INFORMATION	1		0		1		1		1		0		0	
CODE SEQUENCE	a	a^*	$\bar{a}$	$\bar{a}^*$	a	a^*	a	a^*	a	a^*	$\bar{a}$	$\bar{a}^*$	$\bar{a}$	$\bar{a}^*$
FREQUENCY	f_1	f_2	f_1	f_2	f_1	f_2	f_1	f_2	f_1	f_2	f_1	f_2	f_1	f_2

Fig. 3.

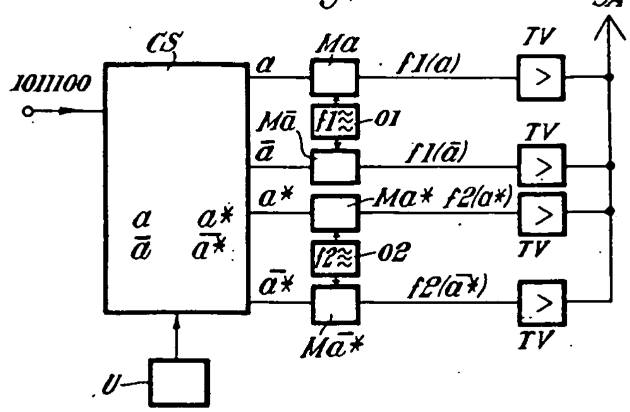
SA
CS
Ma
TV
1011100
a
f1(a)
Mā
f1≈
01
ā
f1(ā)
TV
a*
Ma*
f2(a*)
a
a*
ā
ā*
TV
f2≈
02
ā*
f2(ā*)
TV
Mā*
U

Fig. 4.

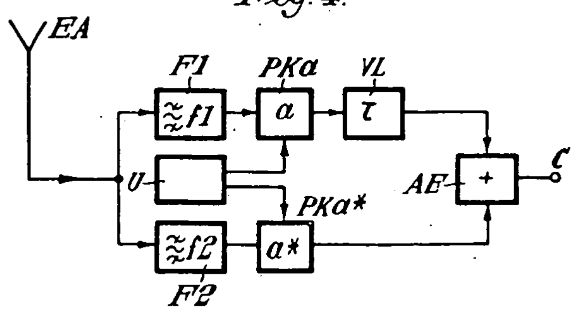
EA
F1
PKa
VL
≈f1
a
τ
C
U
AE
+
PKa*
≈f2
a*
F2

Fig. 5.

PARTIAL SIGNAL IN	CHANNEL I	(aa)	$(a\bar{a})$	(aa)	(aa)	(aa)	$(a\bar{a})$	$(a\bar{a})$
	CHANNEL II	(a^*a^*)	$(a^*\bar{a}^*)$	(a^*a^*)	(a^*a^*)	(a^*a^*)	$(a^*\bar{a}^*)$	$(a^*\bar{a}^*)$
OUTPUT SIGNAL PROFILE								
RECEIVED CODE INFORMATION		1	0	1	1	1	0	0

Fig. 6.